

ON THE TRANSMISSION OF WALSH MODULATED MULTIPLEX SIGNALS

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Introduction

The carrier frequency systems customary in communication engineering transmit information in the frequency multiplex and use circular functions as carriers. The respective underlying principle is also transferable to the system of orthogonal Walsh functions. The theory of the signal multiplexing technique based on the use of Walsh carriers as functions is dealt with in [1]. A number of possible set-ups of multiplex systems and various modes of operation are described in [2].

By way of theoretical deliberations it was shown that a sequence system is capable of transmitting sequence-limited signals without any distortion provided the system is composed of ideal components and provided a transmission channel is used which is matched to the sequence multiplex signal. Moreover, also signals of limited frequency bandwidth can correctly be transmitted with such a system if appropriate matching circuits inserted before the sequence multiplex equipment transform the information into pseudo sequence-limited signals in consideration of the sampling theorem and if other additional circuits re-transform the signals to their original shape after the transmission.

The set-up of a standard multiplex equipment is shown in Fig. 1. Its functioning can be seen from the course of the signal diagrams at different stages in the system.

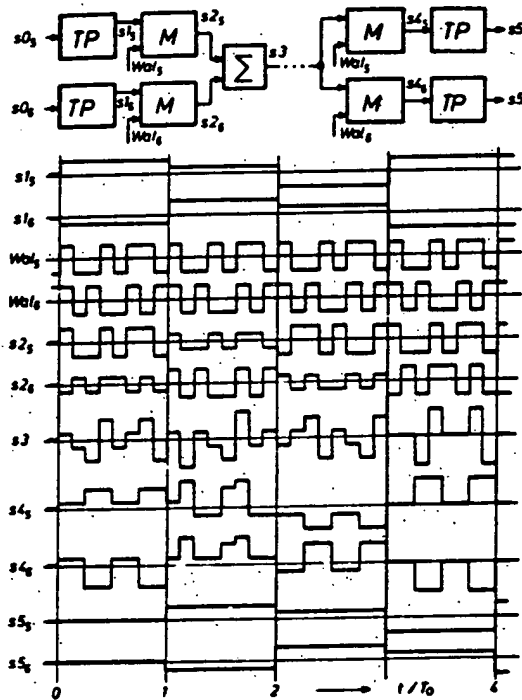


Fig. 1: Principle of a sequence multiplex system
TP sequence low-pass filter,
M multiplier

Distortion of Signals and Crosstalk

In contrast to the conditions prevailing in the case of a multiplex transmission under ideal circumstances, signal distortion and crosstalk will generally appear whenever real system components are used. Even if the transmitter and the receiver are made up of distortion-free ideal components there will be some distortion due to the fact that the bandwidth of customary transmission media is always finite and due

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to differences in the synchronism between transmitter and receiver. Both cause distortions of the signal transmitted as well as crosstalk on adjacent channels.

The subsequent investigations are based on the assumption of linear transmission channels with low-pass characteristic. Here, Gaussian and rectangular-shaped transmission factors with linear phase response are taken as borderline cases of possible frequency limitation. They approximate extreme real conditions. Although these assumptions do not lead to causal systems they yield experience which can suitably be employed for assessing the properties of realistic equipment. The test signal employed for the determination of the system behaviour is a pulse whose duration equals the time base T_0 as used in the multiplex system. It is the "quantum" of a signal of limited frequency bandwidth and it permits the formation of any series of signals. The system behaviour opposite other input signals can, therefore, be derived from the respective superposition of the results obtained for the test signal since the multiplex system and the channel are both linear arrangements.

Standard Multiplex System

Fig. 2 shows the set-up of a simple frequency multiplex equipment. It is similar to the arrangement presented in Fig. 1 and it also evaluates the transmitted multiplex signal in the receiver during the demodulation process by integration over T_0 .

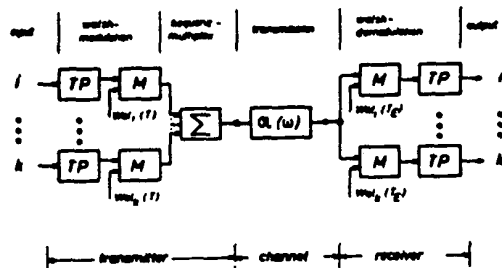


Fig. 2: Principle of a standard multiplex system

The distortions occurring in a 4-channel system with accurate synchronization between transmitter and receiver are plotted in the Figs. 3

and 4. Fig. 3 shows the amplitude of signal sa_{11} at the output 1 of the system which is produced by the test signal se at the input 1 of the system in dependence of the cut-off frequency F_g of the transmission channel. In this case, a rectangular pass band was assumed. Fig. 4 illustrates the signal distortions for a channel with a Gaussian type of transmission factor. The Figs. 5 and 6 show the maximum crosstalk from channel 1 to channel j as produced by se due to frequency limitation in the transmission path in the case of a rectangular and Gaussian transmission factor. In all four diagrams $F_g = T_0 \cdot f_g$ is a parameter normalized to the time base T_0 . If the time base is assumed to be $125 \mu s$ then the expression reads: $f_g = 8 \cdot F_g \text{ kHz}$.

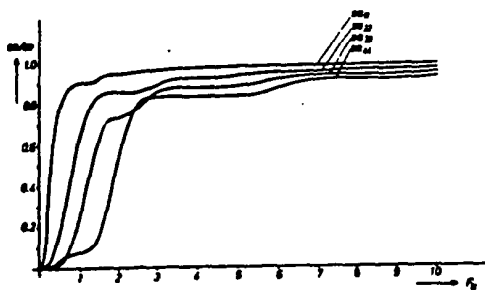


Fig. 3: Output sa_{11} caused by a rectangular shaped channel

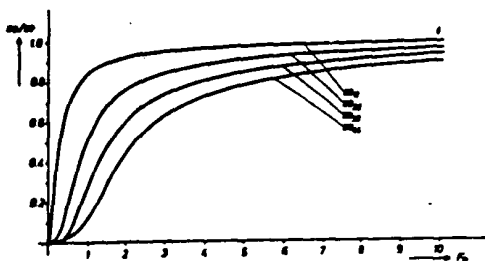


Fig. 4: Output sa_{11} caused by a Gaussian shaped channel

The diagrams indicate that with rectangular limitation of the frequency band less signal distortion and more crosstalk is obtained than with a band limitation of the Gaussian type. For low-distortion transmission, the standard frequency multiplex equipment requires a channel of very large frequency bandwidth.

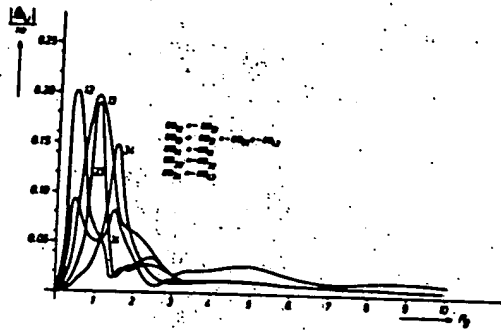


Fig. 5: Crosstalk caused by a rectangular shaped channel

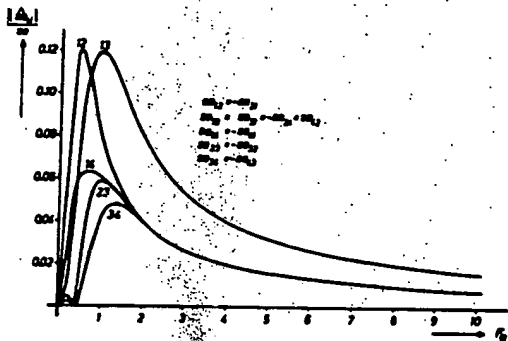


Fig. 6: Crosstalk caused by a Gaussian shaped channel

The results obtained refer to a multiplex equipment of accurate synchronization. There, the frame clock controlling the sequency low-pass filter and the interval of orthogonality of the Walsh carriers both in the transmitter and in the receiver are not delayed with respect to time. Moreover, the frame clocks of transmitter and receiver are synchronous and the time delay of the signals was taken into account accordingly in the calculations. In the case of real systems this ideal condition generally is not given. By an appropriate set-up of the transmitting and receiving equipment it can, however, be achieved that the frame clock and the pattern of the Walsh carriers coincide with sufficient accuracy. The exact phase-locked coupling of the synchronization between transmitter and receiver, on the other hand, is only possible within certain limits. The investigation of the effects of this type of synchronization errors on the system response shows that it also causes signal distortions and crosstalk. Their extent depends on the

limitation of the frequency bandwidth of spectrum of the multiplex signal and differs on the individual channels.

Transmission errors can be reduced if the multiplex signal transmitted is sampled at appropriate times and if it is restored to its original steplike shape prior to the demodulation in the receiver. This can be achieved by means of a sampling and holding circuit provided at the input of the receiver. The study of this extended type of multiplex equipment indicates a clear improvement of the system behaviour as against the standard multiplex equipment. For a low-distortion transmission the extended system does, however, always require a channel of large frequency bandwidth and remains sensitive to synchronization errors.

Sequency Multiplex System With PAM

The above mentioned investigations showed that a direct transmission of Walsh modulated signals via customary frequency limiting media leads to errors which cannot be neglected. The origin of these errors lies in the shape of the multiplex signal. The system response can be improved if this signal is appropriately matched to the characteristics of the channel. One possibility of achieving this is to subject the sequency multiplex signal to an additional pulse amplitude modulation process before the transmission. Fig. 7 shows such an extended multiplex equipment. According to this scheme, the Walsh multiplex signal modulates the amplitude of the pulse carrier $P(T)$. Following the transmission of the PAM signal the receiver restores the sequency multiplex signal to its original shape by regenerating it from the individual pulses with the aid of a sampling and holding circuit. During the regeneration an additional amplification of the pulse amplitudes is required. It compensates the reduction of the pulse amplitudes which is inevitably obtained whenever pulses pass through a low-pass filter having the cut-off frequency F_g . In the case of narrow pulses the amplification v must be inversely proportional to F_g .

The distortions occurring in a system of 4 channels with exact synchronization between transmitter and receiver are shown in Fig. 8 and Fig. 9 for rectangular and Gaussian channel



Fig. 7:

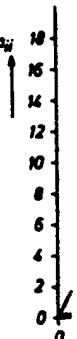


Fig. 8:



Fig. 9:

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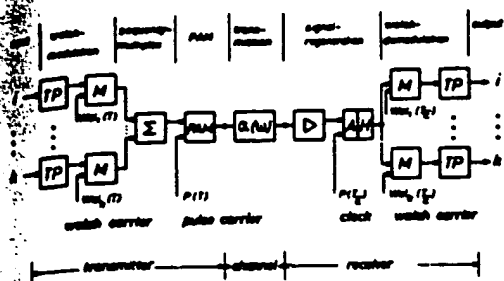


Fig. 7: Principle of a sequence multiplex system with PAM

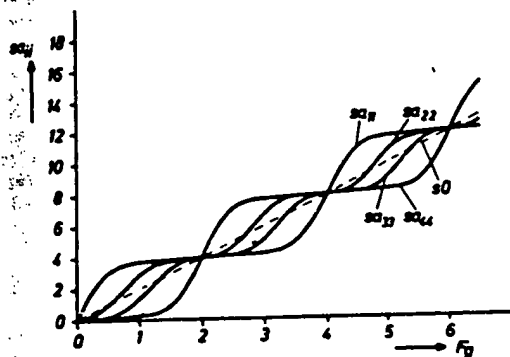


Fig. 8: Output s_{i1} caused by a rectangular shaped channel

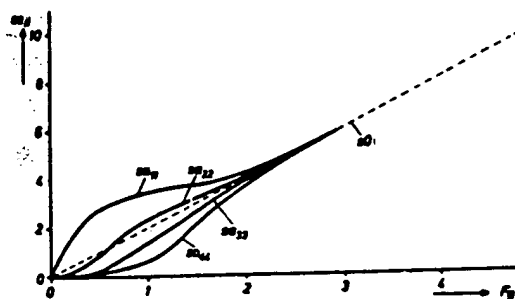


Fig. 9: Output s_{i1} caused by a Gaussian shaped channel

transmission factors. For the relevant calculations a value of $T_0/256$ was selected for the width of the individual rectangular pulses of the pulse sequence $P(T)$. In addition to the signals $s_{i1} = g(F_g)$ also an undistorted signal amplitude $s_0 = g(F_g)$ is plotted in both Figures. It could be measured at the output of the receiver provided the amplification had the value 1. Fig. 8 illustrates that the system does not cause any distortion

of signals if the rectangular channel frequency bandwidth F_g is even-numbered. Even if the channel is assumed to have a transmission factor of the Gaussian type any amplitude distortions in the signals s_{i1} will disappear very quickly as can be seen from Fig. 9.

The crosstalk values determined for the system are plotted in the Figs. 10 and 11. The diagrams indicate that the crosstalk disappears under the same frequency conditions where also the signal distortions in s_{i1} become negligible.

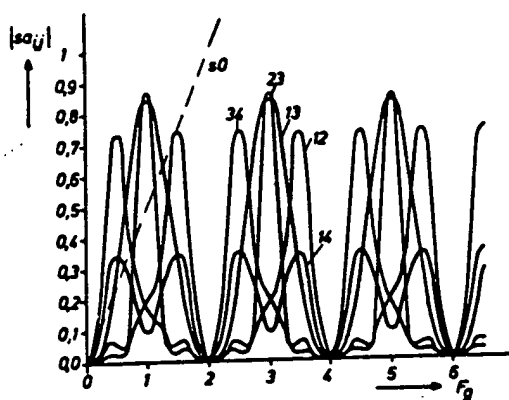


Fig. 10: Crosstalk caused by a rectangular shaped channel

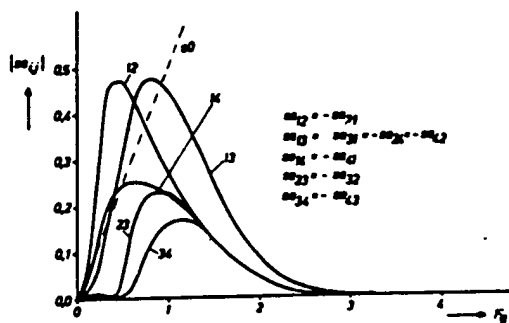


Fig. 11: Crosstalk caused by a Gaussian shaped channel

The favourable system characteristics offered by a transmission equipment according to Fig. 6 become all the more apparent if the thus normalized values for the signal distortions and for the crosstalk are compared to the respective parameters of the standard multiplex system.

The behaviour of the multiplex equipment deteriorates as soon as there are disturbances in the synchronism between transmitter and receiver. An example is given in Fig. 12 where the percentage of the signal distortion s_{11} with the cut-off frequencies $F_g = 2$ and $F_g = 4$ as parameters is plotted over the time shift τ/T_0 in the synchronism. Further details concerning the behaviour of sequency multiplex equipment with additional pulse amplitude modulation can be taken from [3].

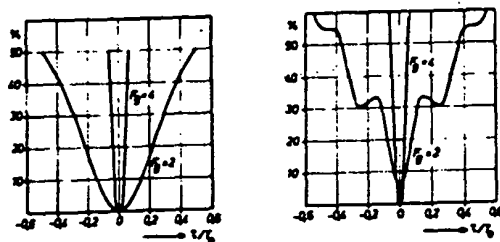


Fig. 12: Interference of the output s_{11} by synchronization delay
left: rectangular shaped channel
right: Gaussian shaped channel

Summary

It was shown that a direct transmission of Walsh modulated signals via channels with low-pass characteristic generally leads to signal distortions and crosstalk. The amount of interference obtained during transmission strongly increases with decreasing frequency bandwidth. Disturbances in the synchronism between transmitter and receiver also result in signal distortion. The theoretically determined system behaviour was actually confirmed by measurements made with a sequency multiplex equipment.

An improvement of the transmission quality is possible by matching the multiplex signal to the channel characteristics. This can, for example, be achieved by means of an additional pulse amplitude modulation process. The investigation of such an extended sequency multiplex system shows that the transmission errors disappear if exact synchronism is ensured and if an appropriate channel bandwidth is selected.

References

- [1] Harmuth, H.F.: Transmission of Information by Orthogonal Functions. Springer Verlag Berlin, Heidelberg, New York, 1969
- [2] Hübner, H.: Analog und Digital Multiplexing by Means of Walsh Functions Symposium and Workshop, Naval Research Laboratory and University of Maryland, March 31. - April 3. 1970, Washington D.C.
- [3] Lovis, W.: Berechnung der Ausgangssignale an einer Sequenz-Multiplexeinrichtung mit zusätzlicher Puls-Amplituden-Modulation Thesis submitted to the Institute for General Communications, Technische Hochschule, Darmstadt, Western Germany, December 8. 1969.

The Walsh functions are the most important functions for their use in being investigated experimentally. This has been discussed in general, but not in detail, in the paper to be published by the author.

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